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Advancements in searches for third-generation supersymmetry using the ATLAS detector

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Summary. — The long search for supersymmetric particles in high-energy physics experiments is leading to the exclusion of huge portions of the parameters space available for the masses of third-generations squarks. On the study of these states is based the search of a solution to the hierarchy problem in the Standard Model (SM); either the confirmation or the exclusion of their existence at masses $\mathcal{O}$(1TeV) will be the base to the evolution of the high-energy physics in the upcoming decades. An overview of results achieved by the ATLAS experiment during Run-II in *pp* collisions with centre-of-mass energy of 13 TeV is presented in the following and specific cases of production and decay of top and bottom squarks will be discussed.

1. – Introduction

Searches for supersymmetric (SUSY) partners of the SM particles have always been one of the main focuses of the ATLAS experiment [1], since the confirmation of their existence could potentially explain several inconsistencies between the current description of high-energy physics and experimental data. In particular, third-generation squarks are expected to be not too much heavier than the $\mathcal{O}$ (TeV), making the experimental observation of its production and decay at the LHC experiments possible.

2. – Third-generation kinematics

Dedicated searches for direct $\widetilde{t}_1$ pair production are common in high-energy physics experiments and are usually optimized for the simplified decay:

$$\widetilde{t}_1 \to t + \widetilde{\chi}_1^0, \tag{1}$$

where $\widetilde{\chi}_1^0$ is the lightest neutralino, since the current limit posed by ATLAS on the gluino mass excludes the decay in gluino. If $m_{\widetilde{t}_1} - m_{\widetilde{\chi}_1^0} < m_t$, the stop $\widetilde{t}_1$ can only

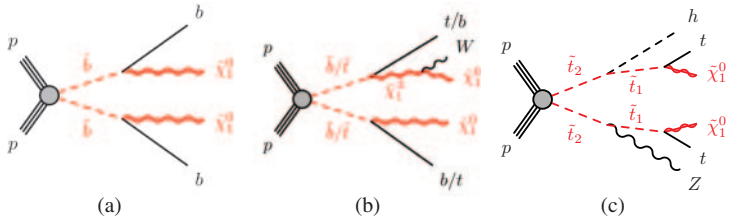

Fig. 1. – Diagrams for the third-generation squark pair production processes considered: (a) $\widetilde{b}_1 \to b\widetilde{\chi}_1^0$ (zero-lepton channel), (b) $\widetilde{q} \to q\widetilde{\chi}_1^0$ or $\widetilde{q} \to q'\widetilde{\chi}_1^\pm$ (Charged-lepton channel, $q = b, t$) and (c) $\widetilde{t}_2 \to \widetilde{t}_1 Z/h$ (StopZh search).

decay in $\widetilde{t}_1 \to b + W + \widetilde{\chi}_1^0$, $\widetilde{t}_1 \to c + \widetilde{\chi}_1^0$ or $\widetilde{t}_1 \to b + f + f' + \widetilde{\chi}_1^0$, but couplings may favour the decay in either charginos or heavy neutralinos: $\widetilde{t}_1 \to t + \widetilde{\chi}_2^0$ / $\widetilde{b}_1 \to b + \widetilde{\chi}_2^0$ or $\widetilde{t}_1 \to b + \widetilde{\chi}_1^\pm$ / $\widetilde{b}_1 \to t + \widetilde{\chi}_1^\pm$. Current searches exclude $\widetilde{t}_1$ masses up to 1 TeV at 95% CL.

3. – Third-generation searches

Results obtained by various ATLAS third-generation SUSY searches are summarised in the following. All the searches take advantage of simplified models and are performed on 36.1 fb^{-1} of data in pp collisions with a centre-of-mass energy $\sqrt{s} = 13$ TeV.

3˙1. *Sbottom pair production.* – In realistic minimal SUSY extensions of the SM at least one sbottom state is expected to have a mass between the two stop eigenstates; a search for direct $\widetilde{b}_1$ pair production, targeting two simplified models, has been performed [2]: *Zero-lepton decay channel:* the sbottom $\widetilde{b}_1$ can only decay in (fig. 1(a))

$$\widetilde{b}_1 \to b + \widetilde{\chi}_1^0. \tag{2}$$

Events are selected if no lepton (e, μ) with $p_{\text{T}} > 10$ GeV is present in the final state, at least two jets are b-tagged, missing transverse momentum $E_{\text{T}}^{\text{miss}} > 200$ GeV.

Charged lepton channel: the sbottom $\widetilde{b}_1$ and the stop $\widetilde{t}_1$ may only decay in either (fig. 1(b)):

$$\widetilde{b}_1/\widetilde{t}_1 \to b/t + \widetilde{\chi}_1^0 \qquad \widetilde{b}_1/\widetilde{t}_1 \to t/b + \widetilde{\chi}_1^\pm \tag{3}$$

with $\widetilde{\chi}_1^0$ and $\widetilde{\chi}_1^\pm$ almost degenerate in mass $m_{\widetilde{\chi}_1^\pm} - m_{\widetilde{\chi}_1^0} = 1$ GeV. Events are selected if they have exactly one lepton passing quality cuts in the final state, two jets are b-tagged and $E_{\text{T}}^{\text{miss}} > 200/250$ GeV.

In both cases, three signal regions (SRs) have been set up, with cuts optimized to target mass models with different mass splitting between $\widetilde{b}_1$ and $\widetilde{\chi}_1^0$. No significant excess was observed in the SRs thus excluding $\widetilde{b}_1$ and $\widetilde{t}_1$ masses as shown in fig. 2.

3˙2. *Stop pair production.* – The presented study [3] targets the direct pair production of two $\widetilde{t}_2$ and the subsequent decay of each of them in one of two possible simplified decay models (fig. 1(c)):

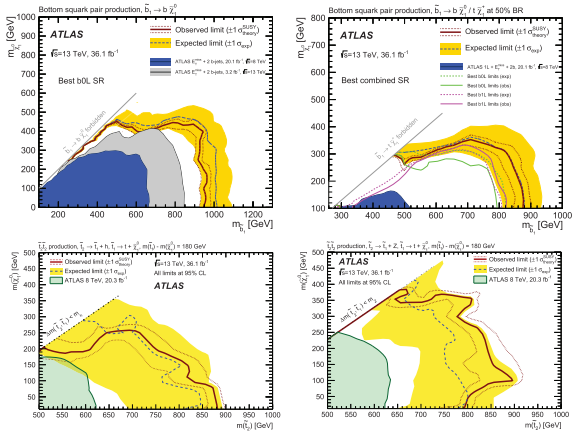

Fig. 2. – Exclusion limits at 95% CL for sbottom searches with no leptons in the final state (a) and a charged lepton in the final state (b) as well as $\widetilde{t}_2$ in a $\widetilde{t}_1$ decay with a Z boson (c) and a Higgs boson (d).

Stop in Z decay channel: $\widetilde{t}_2$ can only decay in

$$\widetilde{t}_2 \to \widetilde{t}_1 + Z \to t + \widetilde{\chi}_1^0 + \ell\bar{\ell}. \tag{4}$$

Events are selected if at least three leptons, passing quality cuts, are present in the final state, as well as a b-tagged jet and $E_{\mathrm{T}}^{\mathrm{miss}} > 100, 140, 180\,\mathrm{GeV}$ (depending on the mass model). Due to the high impact of fake and non-prompt leptons, the leptonic background has been estimated with the data-driven matrix method.
Stop in h decay channel: the heavy stop $\widetilde{t}_2$ can only decay in

$$\widetilde{t}_2 \to \widetilde{t}_1 + h \to t + \widetilde{\chi}_1^0 + b\bar{b}. \tag{5}$$

Events are selected if only one or two leptons, passing quality cuts, are present in the final state, as well as at least three b-tagged jets and $E_{\mathrm{T}}^{\mathrm{miss}} > 120, 150\,\mathrm{GeV}$ (depending on the mass model).

The searches in both channels are restricted to a narrow kinematic region where $m_{\widetilde{t}_1} \simeq m_{\widetilde{\chi}_1^0} + m_t$. In both cases three SRs, optimized for different mass splitting between $\widetilde{t}_2$ and $\widetilde{t}_1$, have been set up. No significant excess has been observed in the SRs thus excluding $\widetilde{t}_2$ and $\widetilde{t}_1$ masses as shown in fig. 2.

4. – Conclusions

A wide spectrum of analyses performed by the ATLAS Collaboration focuses on searching signals of third-generation squark production in pp collisions at the LHC. No relevant deviations from the SM predictions have been observed so far in any of the decay channels considered by the analyses thus pushing forward the lower limits for the masses of light third-generation squarks ($\widetilde{t}_1, \widetilde{t}_2, \widetilde{b}_1$).

REFERENCES

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